

# RHIC ZDC Rates and Corrections

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## 1 Introduction

There have been several calculations of pileup and accidental coincidence rates at RHIC and the Tevatron. In this calculation we take the approach that the Zero Degree Calorimeter (ZDC) cross sections should be reliable enough that we can calculate the rates for all species, at all beam energies and all intensities. We show that, in any case, our calculation gives a straightforward procedure to get the "true" coincidence rates which depends only weakly on your confidence in the physical cross sections.

This approach might be useful during the low energy scan because it gives a prescription for calculating the rates there also.

## 2 Neutron production in pp

The pp and AuAu cross sections are, by now, well known except for the pp double arm cross section. For the latter we use a simple model which does surprisingly well on our measured rates during Run 9 at 100 and 250 GeV beam energy.

There are a number of measurements of the forward inclusive neutron cross section at ISR, FNAL, HERA and SPS. We also now have preliminary results in PHENIX. The agreement among the experiments is not very good and the  $p_t$ -slope measurement, which is most critical for this rate calculation, is limited in PHENIX and ISR by our small angular coverage. We adopt the HERA fits to their data which are more-or-less an average of the other data. Then

$$\frac{d\sigma}{dx_F} = \frac{(2\pi)}{x_F} \int E \frac{d^3\sigma}{dp^3} p_t dp_t \rightarrow \sigma_{\text{non-diffractive}} * < \text{Acceptance}(P_{\text{beam}}) > \quad (1)$$

and the acceptance is calculated using the HERA fit to their  $p_t$  distribution:

$$E \frac{d^3\sigma}{dp^3} \propto 16 * e^{-b p_T^2} \quad (2)$$

The neutron acceptance is simply given by the pt cutoff coming from the ZDC acceptance angle. The acceptance depends simply on  $x_F$ , which is uniformly distributed. The acceptance,  $A$ , averaged over all  $x_F$  is given by

$$\theta_{max} = \frac{5cm}{18meters} \quad (3)$$

$$A = 16 \int_0^{pl*\theta_{max}} pt * e^{-8*pt^2} dpt \quad (4)$$

$$A_{Mean} = 0.45 \int_{0.06}^1 A(pl = pbeam \times x) dx \quad (5)$$

where the lower limit of integration corresponds to the energy threshold on the ZDC. This threshold is usually 15 GeV so, at 250 GeV, the lower limit is  $x_F=.06$ .

The very simple model for the 2 arm cross section is that it is simply given by the square of the mean acceptance. The factor of .45 in eqn. 5 reflects the fact that, on average, 45% of forward baryons are neutrons.

In Table 1 we compare predictions of this model with Run 9 rates. The agreement is very good. A similar exercise with the first data from LHC also gave consistent results.

Table 1: Comparison with Run 9 Rates

	$\sqrt{s}=500$ GeV coincidence	singles	$\sqrt{s}=200$ GeV Coincidence	Singles
PHENIX measured	78000	573000	3200.	64000
This Calculation	73796.5	595253.	3203.48	63412.5

There is very little that could alter these cross sections from run to run at RHIC. The low energy spectrum is very likely to also contain  $\gamma$ 's and the ZDC thresholds do change a bit. But we are insensitive to the low end because the ZDC acceptance deteriorates so badly as  $x_F \rightarrow 0$ .

More details on this model can be found in Ref. [1].

The basic cross sections at  $\sqrt{s}=500$  GeV, obtained using ref. 1, are then

$$\sigma_{nondiffractive} = 32mb \quad (6)$$

$$\sigma_{2-arm} = \sigma_{nondiffractive} * \text{MeanAcceptance}(250)^2 \quad (7)$$

$$\sigma_{1-arm} = \sigma_{nondiffractive} * \text{MeanAcceptance}(250) - \sigma_{2-arm} \quad (8)$$

$$\sigma_N = \sigma_{1-arm} \quad (9)$$

$$\sigma_S = \sigma_N \quad (10)$$

$$\sigma_{NS} = \sigma_{2-arm} \quad (11)$$

### 3 Heavy Ions

For heavy ion collisions the 2-arm cross sections are given by the Glauber cross section and Mutual Coulomb Dissociation. The sum of these was calculated in Ref. [2]. The inclusive single arm cross section due to Coulomb interactions was also calculated. For AuAu at 100 GeV/n, the corresponding cross sections are 7.2, 3.0 and 95 barns- see Figure 5. The energy dependence of these cross sections is negligible when compared to the strong acceptance dependence on beam energy. At full energy the acceptance, even averaged over impact parameter, is essentially 100%. The low energy behavior, relevant for Run 10 is given in Ref. [3]. Calculation of the cross section for other species is straightforward.

### 4 pp rates

The ZDC scaler rates depend non-linearly on Luminosity because of the bunch structure. For higher bunch frequencies the Luminosity at which pileup effects, such as accidental coincidences, become important goes up. These days we could use a revolution frequency of 78.2 kHz with 111 interacting bunches per revolution. Then, in all rate calculations, it is simpler to calculate the probability for 1 or more counts of a given type in any given bunch.

$$f_{\text{rev}} = 78.3\text{kHz}, f_{\text{bunch}} = 120f_{\text{rev}}, f = 111 * f_{\text{rev}} \quad (12)$$

$$k = 0 \quad (13)$$

$$\mu = \frac{\mathcal{L} * \sigma}{f} \quad (14)$$

$$R = f * \left(1 - \frac{e^{-\mu} \mu^k}{k!}\right) = f * (1 - e^{-\mu}) \quad (15)$$

On the RHIC scalers we count 2 quantities, the ZDC "or" and the coincidence. The probability of a count in any crossing is given by the above cross sections. By our definition, the "or" probability is proportional to the sum of the North, South and coincidence cross sections. So

$$\mu_{N \oplus S} = \frac{\mathcal{L} * (\sigma_S + \sigma_N + \sigma_{NS})}{f} \quad (16)$$

It is trivial to calculate the luminosity from this rate, however this rate is more sensitive to backgrounds than the coincidence. So we would like a second redundant calculation of the Luminosity from the coincidence rate.

The Luminosity calculation from coincidences is a little more complicated because at high luminosity there are two contributions:

$$R_{\text{NS}} = f * \left\{ \left(1 - e^{-\mu_{\text{NS}}[\mathcal{L}]}\right) + \left(1 - e^{-\mu_N[\mathcal{L}]}\right)^2 * e^{-\mu_{\text{NS}}[\mathcal{L}]} \right\} \quad (17)$$

the second term gives the fraction of bunches that don't have a true coincidence but instead have a random coincidence of N and S hits.

It is more complicated to calculate the luminosity from this relation but it turns out that with  $\mu$  given by the frequency at PHENIX and using the pp cross sections at  $\sqrt{s}=500$  GeV, a power series expansion quickly converges and a quadratic is good enough up to  $\mathcal{L} \cong 3 * 10^{32}$ . ie.

$$R_{\text{NS}}/f = .02\mathcal{L} + 0.0034\mathcal{L}^2 \quad (18)$$

where  $\mathcal{L}$  is in units of  $10^{32}$ .

This calculation is very powerful because, since Run 1, there has been no such thing as 2-arm background. There is just the pileup effect we've calculated.

There are a number of ways you could use this redundancy. Maybe the most straightforward is to simply calculate the RHIC background rates, which are probably due to beam-gas interactions and beam losses. For example, you could solve for the equivalent "background cross section" in:

$$\mu_{N \oplus S} = \frac{\mathcal{L} * (\sigma_S + \sigma_N + \sigma_{\text{NS}} + \sigma_{\text{background}})}{f} \quad (19)$$

Some aspects of the pp rates are illustrated in Figures 1 and 2.

## 5 Heavy Ion Rates

The same calculation applies also to heavy ion runs. The cross sections are larger, while the luminosities are lower. Under typical running conditions the rates are low enough that these calculations can be done more approximately. The expected rates are shown in Table 3.

## References

- [1] S. White, Neutron Production and ZDC Acceptance, ATLAS internal note and [arxiv.org/pdf/0912.4320](http://arxiv.org/pdf/0912.4320).
- [2] A. Baltz, C. Chasman, S. White, Nucl.Instrum.Meth.A417:1-8,1998
- [3] M. Strikman, S. White, Beam Fragmentation in Heavy Ion Collision and its Implication for RHIC triggers at low  $\sqrt{s}$ . [arxiv.org/pdf/0910.3205](http://arxiv.org/pdf/0910.3205)

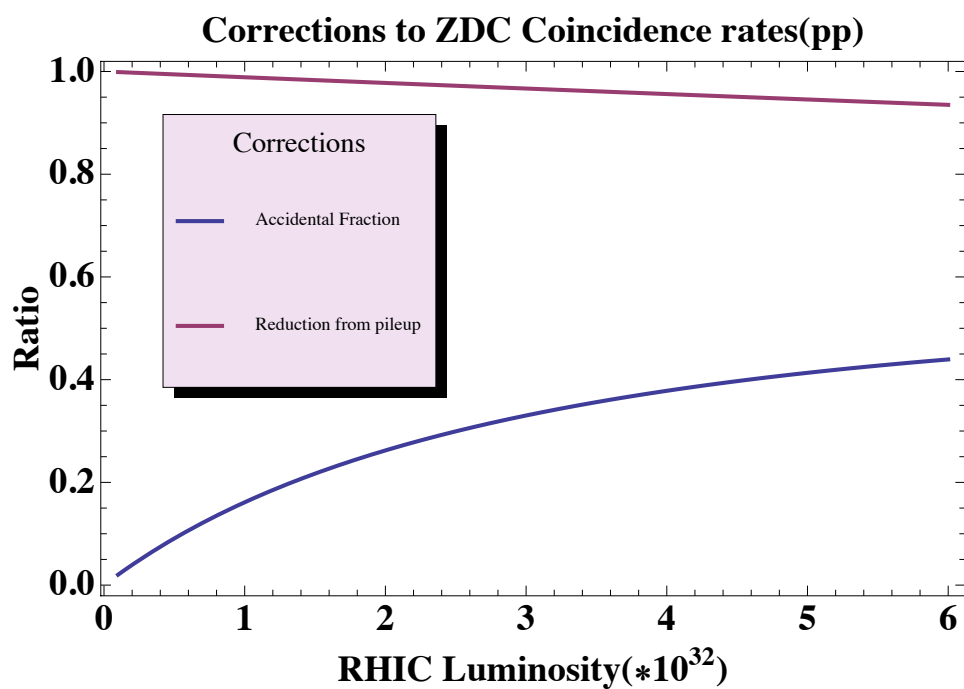


Figure 1: The main corrections to the ZDC coincidence rate at high Luminosity are accidental coincidences and pileup of counts within a bunch.

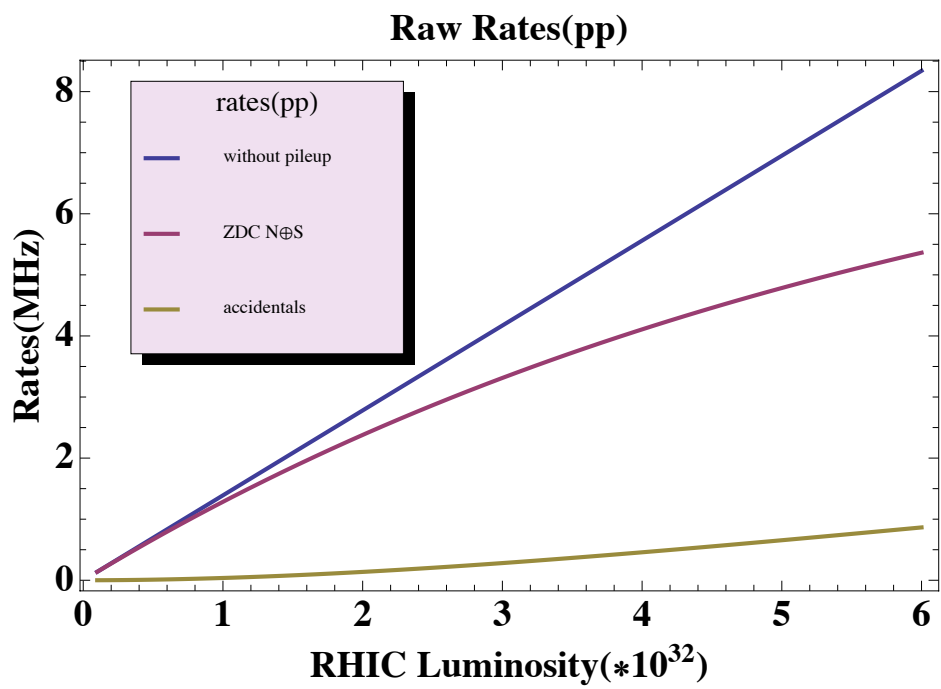


Figure 2: The raw rates as a function of Luminosity.

Table 2: Rates in pp at  $\sqrt{s}=500$  GeV

$\mathcal{L} \times 10^{31}$	North(kHz)	Coinc(kHz)	accidentals(kHz)
1.	78.9511	19.6491	0.780468
2.	157.122	39.2499	3.09109
3.	234.52	58.8024	6.88647
4.	311.153	78.3069	12.1223
5.	387.028	97.7634	18.7552
6.	462.153	117.172	26.743
7.	536.536	136.533	36.0442
8.	610.183	155.846	46.6185
9.	683.102	175.112	58.4264
10.	755.3	194.33	71.4295
11.	826.785	213.501	85.59
12.	897.563	232.625	100.871
13.	967.641	251.702	117.238
14.	1037.03	270.732	134.654
15.	1105.73	289.715	153.085
16.	1173.75	308.651	172.499
17.	1241.1	327.541	192.863
18.	1307.78	346.384	214.144
19.	1373.8	365.181	236.312
20.	1439.17	383.932	259.336
21.	1503.9	402.636	283.187
22.	1567.98	421.295	307.836
23.	1631.43	439.907	333.254
24.	1694.25	458.474	359.414
25.	1756.46	476.995	386.29
26.	1818.05	495.471	413.854
27.	1879.02	513.901	442.082
28.	1939.4	532.286	470.948
29.	1999.18	550.625	500.428
30.	2058.37	568.92	530.498

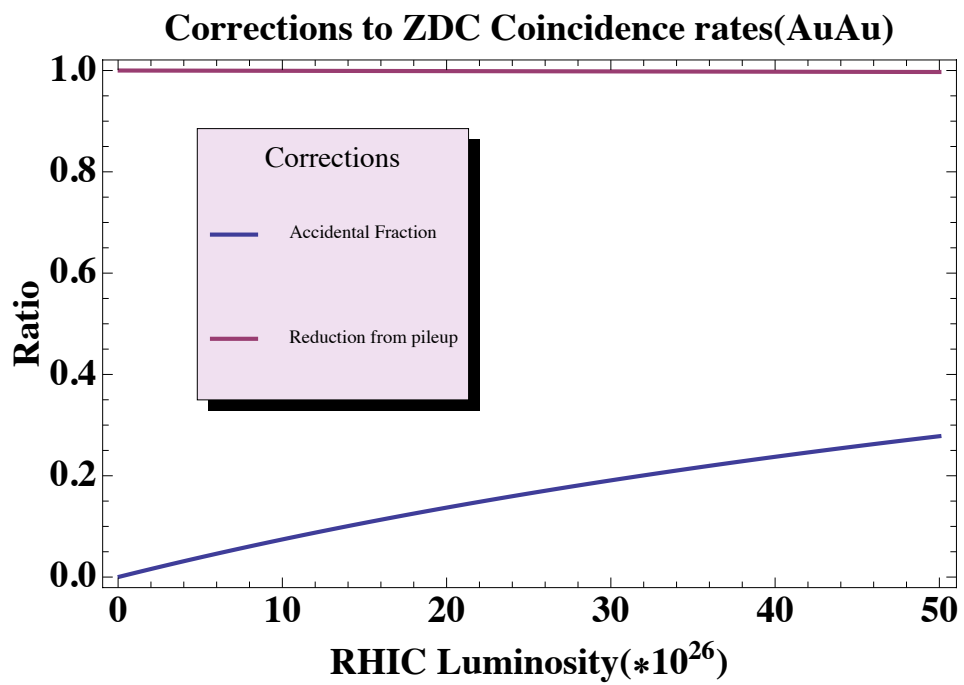


Figure 3: Corrections to the ZDC rates at  $\sqrt{s}=200$  GeV Au-Au.

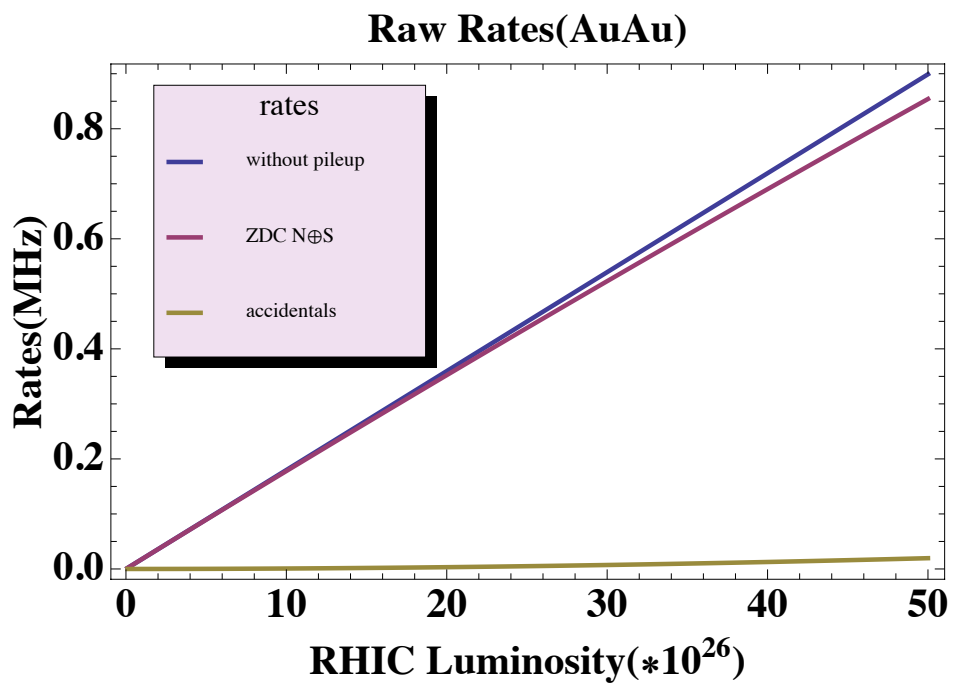


Figure 4: The raw rates as a function of Luminosity for  $\sqrt{s}=200$  GeV Au-Au.

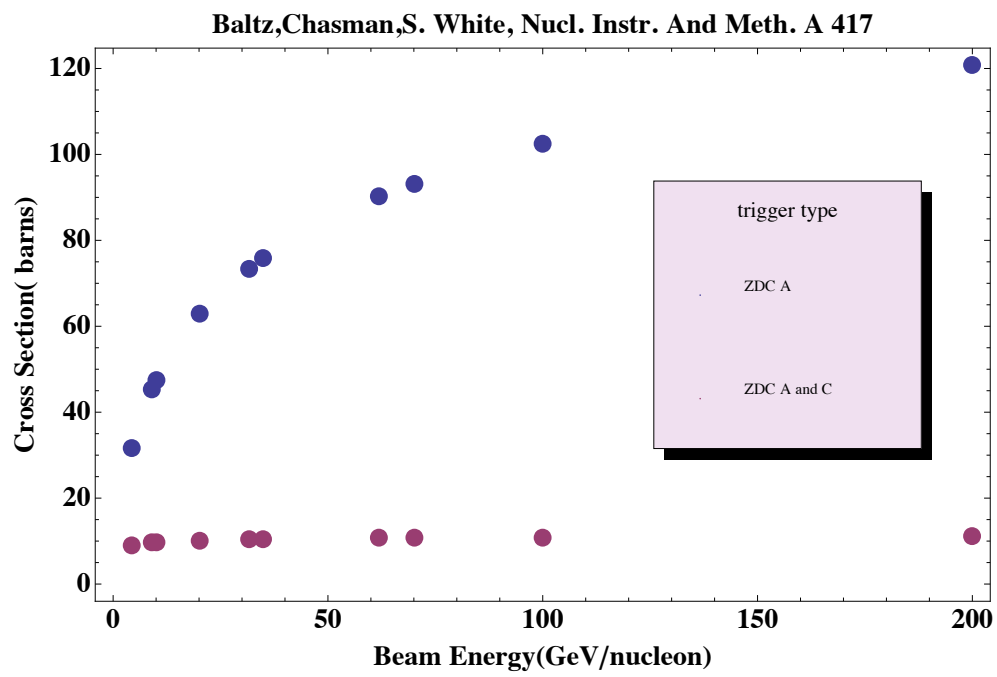


Figure 5: ZDC effective cross section with Au beams vs. cms energy.

Table 3: Rates in AuAu at  $\sqrt{s}=200$  GeV

$\mathcal{L} \times 10^{26}$	North(kHz)	Coinc(kHz)	accidentals(kHz)
1.	17.9614	1.0282	0.0082648
2.	35.8857	2.07278	0.0330231
3.	53.773	3.13368	0.0742208
4.	71.6233	4.21085	0.131804
5.	89.4367	5.30422	0.205719
6.	107.213	6.41376	0.295912
7.	124.953	7.5394	0.402329
8.	142.656	8.68109	0.524918
9.	160.323	9.83878	0.663625
10.	177.953	11.0124	0.818396
11.	195.547	12.2019	0.989179
12.	213.104	13.4073	1.17592
13.	230.625	14.6285	1.37857
14.	248.11	15.8653	1.59707
15.	265.558	17.1179	1.83137
16.	282.971	18.3861	2.08142
17.	300.348	19.6699	2.34717
18.	317.688	20.9692	2.62856
19.	334.993	22.284	2.92555
20.	352.262	23.6142	3.23807
21.	369.496	24.9597	3.56609
22.	386.694	26.3206	3.90954
23.	403.856	27.6967	4.26838
24.	420.983	29.0881	4.64255
25.	438.074	30.4946	5.032
26.	455.13	31.9163	5.43669
27.	472.151	33.353	5.85656
28.	489.137	34.8047	6.29156
29.	506.087	36.2714	6.74164
30.	523.003	37.7529	7.20675